Telecom

Introduction to Optical Communications

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Excerpted from:

Optical Switching and Networking Handbook

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CHAPTER 1

Introduction to Optical Communications

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Welcome to this next installment of the telecommunications made simple writings! When I first started to write in the early 1990s, I was overwhelmed with the amount of work necessary to produce the first book. That was the original *Disaster Recovery Planning for Telecommunications, Data and Networks*, and it was a rather short book. However, immediately after completing the final edit, I swore never to write another book. Well, here we are 10 books later, still saying the same things, but releasing a new one. This time the topic is fiberoptics, fiber networking, and optical switching for your reading enjoyment and understanding. The intent here is to make the technology easy to understand while giving you facts and applications in the state of the industry. Similar to the past books, if you are an engineer looking for technical discussions in the goriest detail, this book is *not* for you. However, if you fall into the following categories, then this is for you:

- Financial analysts trying to understand the cost implications of a fiberoptic network for investment or funding purposes
- Telecommunications administrator trying to understand what everyone is all excited about
- Salesperson in a telecommunications company trying to "walk the walk" and "talk the talk"
- Data processing person trying to get the most bang out of the data revolution
- Supplier of bandwidth needing to understand what the manufacturers are all saying
- "Newbie" in the industry trying to understand the technologies

What is this all about? I keep being asked to do things in my own simple way. I enjoy public speaking, and I enjoy watching people learn. You can tell when they are learning by that expression on their face when the revelation of a concept finally becomes clear. Therefore, I undertook this book on optical networking and switching to try to simplify the overall process of what is going on. Too often the vendors and standards bodies are busy writing standards documents or documentation on how equipment works. They know what they are talking about, so they assume that the readers in the industry also will know what they are saying. Unfortunately, that is *not* true! Probably all of us have picked up a trade magazine and seen a feature article written by some VP of engineering at a local manufacturer. The article presents several different acronyms and offers several opinions about the product or service. Yes, there is merit in the article, but too often there is so much jargon that readers have a tendency to put the article aside. What a sad thing it would be to have a communications industry that cannot communicate. It is for this reason that McGraw-Hill keeps asking for help in offering some semblance of understanding of industry techniques. One hopes that such understanding will result from this book as it has with the past ones.

Transmission System Terms

Before discussing the fiberoptic world, I should at least describe some very basic terms. These will help you to understand the world of fiber. There are many other ways of describing the use of fiber, but these definitions will aid in rudimentary understanding.

Amplifier This device increases the power of an electromagnetic wave, such as sound or light, without distorting it, as shown in Figure 1-1. Your stereo amplifier takes the weak radio signals from the air and boosts them so that they are strong enough to drive the speakers. Amplifiers in fiberoptics systems do almost the same thing—they brighten the light passing through the fibers.

Coaxial cable Coaxial cable is a high-frequency transmission line that is used to send telephone and television impulses. The CATV companies use a single cable to deliver multiple channels of TV by employing a multiplexing technique that separates the signals by frequency. See the representation of coaxial cable in Figure 1-2.

Modulator A modulator is a change agent. This device converts (changes) electrical on/off pulses into sound pulses for voice telephone calls. The modulator in a fiberoptic system does the same thing, except that it converts the electrical pulses into pulses of light, as shown in Figure 1-3. A modulator-demodulator (called a *modem*)

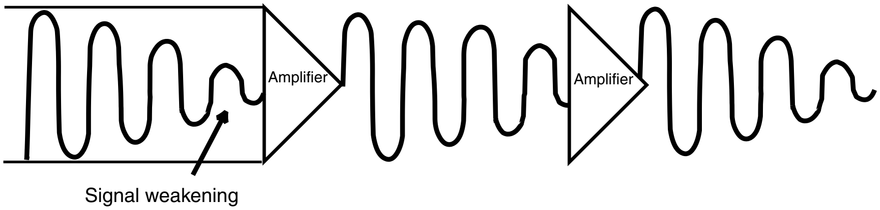


Figure 1-1
Amplifiers boost weak signals.

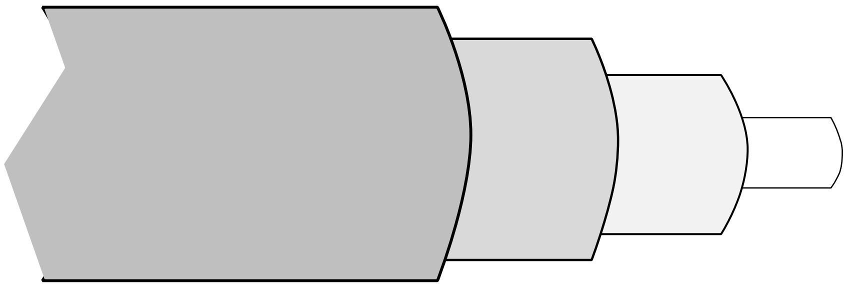


Figure 1-2
Coaxial cables handle high-frequency transmissions especially for TV.

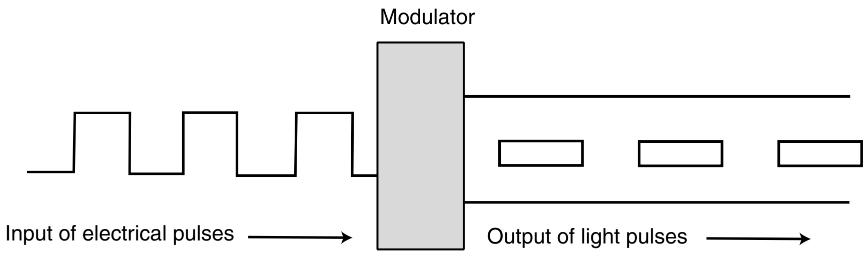


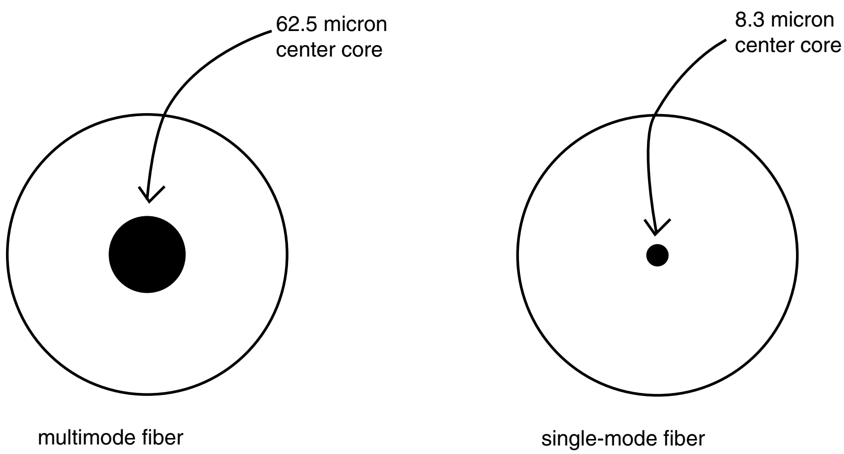
Figure 1-3
A modulator converts the electrical pulses into light pulses.

converts information from one form and back again, depending on the direction.

Laser (*l*ight *a*mplification by *s*imulated *e*mission of *r*adiation) A light source created by exciting atoms, causing them to emit light of a specific wavelength (frequency) in a focused beam. Think of a group of people who are all trying to lift a very heavy object, one at a time. Nothing happens because they individually have little strength. However, if they all get together and lift at the same time, their concentrated strength creates the result. Violà! They lift the heavy object. Doing the same thing with light, by exciting a single light particle individually, the beam is barely visible. However, if you concentrate and excite all the light particles at the same time, you create a very intense light beam.

Multimode fiber This type of fiber is used for hauling traffic over short distances, such as within a building. In optical fiber technology, multimode fiber is optical fiber that is designed to carry light rays on different paths or modes concurrently, each at a slightly different reflection angle within the optical fiber core. Multimode fiber transmission is used for relatively short distances because the modes tend to disperse over longer lengths (this is called *modal dispersion*). Multimode fiber has a larger center core than single-mode fiber. Figure 1-4 offers a comparison between multimode (thick) and single-mode fiber.

Figure 1-4 Comparison of the fiber types



Receiver A receiver is an electronic device that converts optical signals to electrical signals. Your antenna receives radio signals. A fiberoptic receiver—usually an electronics component called a *diode*—similarly receives light signals.

Single-mode fiber This type of fiber is used typically for long distances. Single-mode fiber is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier and is used for long-distance signal transmission. Single-mode fiber has a much smaller core than multimode fiber.

Time-division multiplexing (TDM) A scheme in which numerous signals are combined for transmission on a single communications line or channel. Each signal is broken up into many segments, each having very short duration. The circuit that combines signals at the transmitting end of a communications link is known as a *multiplexer.* It accepts the input from each individual end user, breaks each signal into segments, and assigns the segments to the composite signal in a rotating, repeating sequence. The composite signal thus contains data from all the end users. At the other end of the long-distance cable, the individual signals are separated out by means of a circuit called a *demultiplexer* and routed to the proper end users. Think of a road system where you have a six-lane highway. Suddenly you come to a single-lane bridge. Protocol states that politely, each lane will in turn enable one vehicle to cross the bridge. Therefore, each input (lane) grabs the entire bandwidth (the lane) and passes its traffic (the cars) one at a time. This is shown in Figure 1-5 with the single-lane bridge analogy.

Transmitter Just as a radio transmitter sends out radio signals, an optical transmitter—usually a *light-emitting diode* (LED) or a laser—sends out optical signals.

Wavelength-division multiplexer (WDM) A fiberoptic device used to separate signals of different wavelengths carried on one fiber. Imagine two people talking on the phone at the same time, one with a deep male voice and the other with a high-pitched female voice. You can focus on one person or the other by listening for the deep sounds or the high ones. Similarly, several signals can be sent along an optical fiber using different frequencies (colors) of light. At the receiving end, the WDM "listens" to the different frequencies and separates the different signals. This is shown in Figure 1-6.

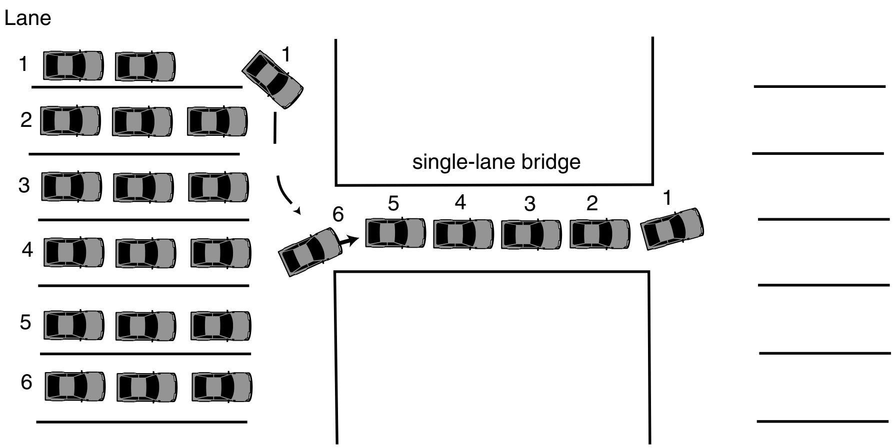


Figure 1-5 Time-division multiplexing enables each input to seize the entire bandwidth for a short duration in rotation.

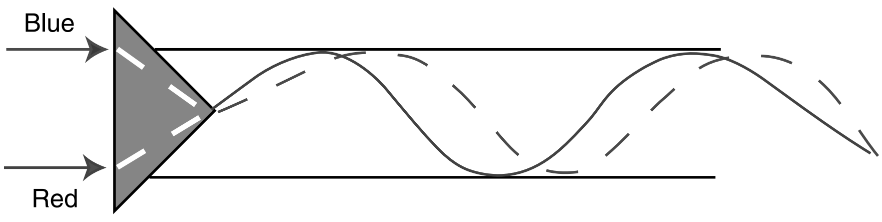


Figure 1-6 Wave-division multiplexing uses different wavelengths (frequencies) of light.

History of Optical and Fiber in Telecommunications

Let's take a trip down memory lane and discuss the use of optical communications in the telecommunications industry from its inception to the development of the various types and modes of fiberoptic systems. The beginning of optical communications is rather interesting. It has always been a belief that if you want to know where things are going, you have to understand where they have been. A little history will help.

Optical communications systems date back to the "optical telegraph" invented by French engineer Claude Chappe in the 1790s. He used a series of semaphores mounted on towers, with human operators relaying messages from one tower to the next. Of course, in order for this to work, the people had to be close enough together to visually see the other messenger's motions. This was not a great service for evening transmission and had some problems with weather conditions (for example, fog, heavy rain, heavy snow, and so on). The system depended on a line-of-sight operation; hence, the towers needed elevation to extend the coverage (albeit, a limited distance between repeaters) and close proximity.

However, the optical telegraph did perform better than hand-carried messages. Alas, by the mid-nineteenth century the system was replaced by the electric telegraph, leaving a scattering of "telegraph hills" as its legacy. The use of electrical transmissions was better suited for communications over distances.

In 1880, Alexander Graham Bell patented an optical telephone system, called the *photophone.* His earlier invention, the telephone, was far more practical and widespread. Bell dreamed of sending signals through the air. Unfortunately, the atmosphere did not carry transmitted light as reliably as wires carried electricity. Light was used for a few special applications, such as signaling between ships, but otherwise, optical communications did not achieve the expected results.

Later, a new technology began to take root that ultimately would solve the problem of optical transmission. It took a long time before it was finally adapted and accepted for voice and data communications. This new development relied on “total internal reflection” that confines light in a material surrounded by other materials with a lower refractive index, such as glass in air. Chronologically, the events leading up to the use of glass began with several steps, as shown in Table 1-1.

Today, more than 90 percent of long-distance data traffic in the United States is transmitted through fiberoptics. More than 15 1/2 million miles of fiberoptic cable has been installed already, all of it using the original design of Maurer, Keck, and Schultz.

Fiberoptics work by using light pulses traveling along glass fibers that are less than the thickness of a human hair to transmit data. These cables are much smaller than conventional copper wires and are able to transmit data at very high speeds, making them ideal for video and audio.

The Demand for Bandwidth

Meanwhile, telecommunications engineers were seeking ways of delivering more transmission bandwidth. Radio and microwave frequencies were already in heavy use. Therefore, the engineers looked to higher frequencies to carry traffic loads, which they expected to continue increasing with the growth of television and telephone traffic. Telephone companies thought video telephones lurked just around the corner and would escalate bandwidth demands even further. In 1964, during the World’s Fair in New York, AT&T introduced an experimental model of the PicturePhone that required a T3 line[1] to transmit motion video across a telephone link (Figure 1-7). The other end of the connection was at Disneyland (in California). The commercial version was introduced in 1970 in Pittsburgh. Despite all the hopes and predictions, the cost and bandwidth demands of this device made it impractical. Moreover, the device was bulky and not user-friendly. However, the seed was planted for the future use of a video conferencing system that would transmit real-time pictures.

[1]A T3 is a multiplexed transmission that delivers 44.736 Mbps of information.

Table 1-1

Timeline for Development of Fiber-Based Systems

1840s	Daniel Collodon and Jacques Babinet showed that light could be guided along jets of water used for fountain displays.
1854	John Tyndall created interest in guided light by displaying light guided by a jet of water flowing from a tank.
1900s	Various inventors realized that bent quartz rods could carry light and patented them as dental illuminators.
1920s	John L. Baird and Clarence W. Hansell patented the idea of using arrays of hollow pipes or transparent rods to transmit images for television or facsimile systems.
1930s	Heinrich Lamm demonstrated image transmission through a bundle of optical fibers. He used his to look inside inaccessible parts of the body in a medical application. He also documented that he could transmit an image through a short bundle of fibers. However, the unclad fibers transmitted the images poorly.
1940s	Many doctors used illuminated Plexiglas tongue depressors.
1951	Holger Møller Hansen applied for a Danish patent on fiberoptic imaging. The Danish patent office denied his application, based on Baird and Hansell's patents.
1954	Abraham van Heel, Harold H. Hopkins, and Narinder Kapanyin separately announced imaging bundles. None of these people made bundles that could carry light very far, but their reports popularized the fiberoptics revolution. The primary innovation was made by van Heel. Early use of fiber was with "bare glass," with total internal reflection at a glass-air interface. Van Heel covered a bare fiber with a transparent cladding with a lower refractive index.
1956	The next step was the development of glass-clad fibers by Lawrence Curtiss while working part time on a project to develop an endoscope to examine the inside of the stomach.
1960	Glass-clad fibers had attenuation of about 1 decibel per meter, which worked well for medical imaging. This was much too high for use in telecommunications.
1970	Maurer, Keck, and Schultz made the first optical fiber with data losses low enough for wide use in telecommunications. It is now capable of transmitting data 65,000+ times faster than regular copper wire methods.

Source: AT&T

Source: Picturephone

Figure 1-7
The PicturePhone was introduced by AT&T in 1964 (AT&T). (For comparison, a 1970s Picture-Phone and a more recent one.)

Serious work on optical communications had to wait for the continuous-wave helium-neon laser. Although air is far more transparent at optical wavelengths than to millimeter waves, researchers soon found that rain, haze, clouds, and atmospheric turbulence limited the reliability of long-distance atmospheric laser links.

By 1965 it was clear that major technical barriers remained for both millimeter-wave and laser telecommunications. Millimeter waveguides had low loss, but only if they were kept perfectly straight; developers thought the biggest problem was the lack of adequate repeaters. Optical waveguides were proving to be a problem. Design groups at Bell Telephone Labs were working on a system of gas lenses to focus laser beams along hollow waveguides for long-distance telecommunications. However, most of the telecommunications industry thought the future belonged to millimeter waveguides.

Optical fibers had attracted some attention because they were analogous in theory to plastic dielectric waveguides used in certain microwave applications. In 1961, developers demonstrated the similarity by drawing fibers with cores so small they carried light in only one waveguide mode. However, virtually everyone considered fibers too “lossy” for communications; attenuation of a decibel per meter was fine for looking inside the body but not for long-haul communications. Telecommunications operated over much longer distances and required loss of no more than 10 or 20 decibels per kilometer.

At the Corning Glass Works (now Corning, Inc.), Robert Maurer, Donald Keck, and Peter Schultz started with fused silica, a material that can be made extremely pure but has a high melting point and a low refractive index. They made cylindrical performs by depositing purified materials from the vapor phase, adding carefully controlled levels of dopants to make the refractive index of the core slightly higher than that of the cladding without raising attenuation dramatically. In September 1970, they announced that they had made single-mode fibers with attenuation at the 633-nanometer helium-neon line below 20 decibels per kilometer.

The Corning breakthrough was among the most dramatic of many developments that opened the door to fiberoptic communications. In the same year, Bell Labs and a team at the Ioffe Physical Institute in Leningrad made the first semiconductor diode lasers capable of emitting a continuous wave at room temperature. Improvements over time allowed for dramatically less fiber loss, aided both by improved fabrication methods and by the shift to longer wavelengths where fibers have inherently lower attenuation.

Early single-mode fibers had cores several micrometers in diameter, and in the early 1970s, this bothered developers. They doubted it would be possible to achieve the micrometer-scale tolerances needed to couple light efficiently into the tiny cores from light sources or in splices or connectors. Not satisfied with the low bandwidth of step-index multimode fiber, they concentrated on multimode fibers with a refractive index gradient between core and cladding and core diameters of 50 or 62.5 microns. The first generation of telephone field trials in 1977 used such fibers to transmit light at 850 nanometers.

These first-generation systems could transmit light several kilometers without repeaters but were limited by loss of about 2 decibels per kilometer in the fiber. A second generation soon appeared using new lasers, which emitted at 1.3 microns. Fiber attenuation was as low as 0.5 decibel per kilometer, and pulse dispersion was somewhat lower than at 850 nanometers. Development of hardware for the first transatlantic fiber cable showed that single-mode systems were feasible, so when deregulation opened the long-distance phone market in the early 1980s, the carriers built national backbone systems of single-mode fiber with 1300-nanometer sources. This technology has spread into other telecommunications applications and remains the standard for most fiberoptic systems.

However, a new generation of single-mode systems found application in submarine cables and systems serving large numbers of subscribers. They operate at 1.55 microns. Fiber loss is 0.2 to 0.3 decibel per kilometer, enabling even longer repeater spacing. More importantly, erbium-doped optical fibers serve as optical amplifiers at this wavelength, avoiding the need for electro-optical regenerators.

Submarine cables with optical amplifiers operate at speeds up to 5 *gigabits per second* (Gbps). These can be upgraded from lower speeds simply by changing terminal electronics. Optical amplifiers also are attractive for fiber systems delivering the same signals to many terminals because the fiber amplifiers can compensate for losses in dividing the signals among many terminals.

The biggest challenge remaining for fiberoptics is economic. Today, telephone and cable television companies can cost-justify installing fiber links to remote sites serving tens to a few hundred customers. Terminal equipment remains too expensive to justify installing fiber all the way to the home, at least for now. Instead, cable and phone companies run twisted-pair wire or coaxial cable from optical network units along the side of the road to individual homes. Time will see how long this lasts, although many people believe that *fiber to the home* (FFTH) is already upon us.

Fiber Justification

Many reasons exist for the initial introduction of fiber, but some of the strongest reasons are as follows:

Bandwidth compared with copper Taken in bulk, it would take 33 tons of copper to transmit the same amount of information handled by 1/4 pound of optical fiber.

Strength The tinsel strength of the fiber is greater than that of steel.

Speed of transmission Fiberoptic networks operate at speeds up to 10 Gbps, as opposed to 1.54 *megabits per second* (Mbps) for copper. Soon, a fiberoptic system will be able to transmit the equivalent of an entire encyclopedia of information in 1 second. Fiber can carry information so fast that you could transmit three television episodes in 1 second.

Immunity to electrical and radiofrequency interference Fiberoptic cables have a greater resistance to electromagnetic noise from items such as radios, motors, or other nearby cables. Because optical fibers carry beams of light, they are free of electrical noise and interference.

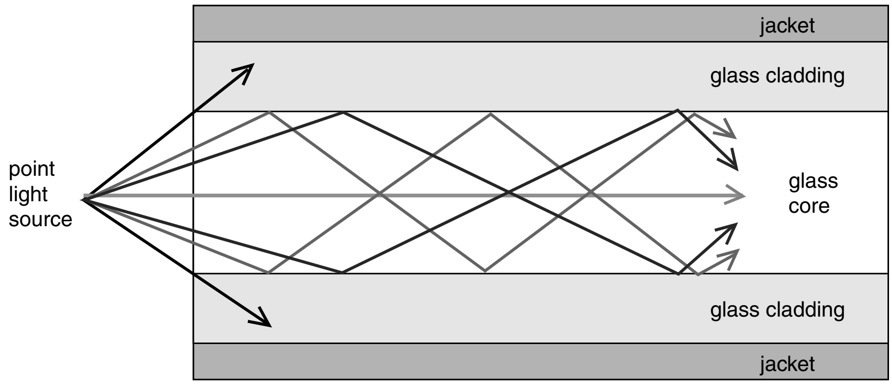
Less weight in installation Fiberoptics have a greater capacity for information, which means that smaller cables can be used. An optical fiber cable the size of an electrical cord can replace a copper cable hundreds of times thicker.

How It Works

A glass tunnel through which light travels is created. When the light hits the cladding, it interacts with and reflects back into the core. Because of this design, the light can "bend" around curves in the fiber, and this makes it possible for the light to travel greater distances without having to be repeated. This is illustrated in Figure 1-8.

The light that travels along the fiber is made up of a binary code that pulses "on" and "off" and determines what information a given signal contains. The advantage of fiber is that these on/off pulses can be translated to video, computer, or voice data depending on the type of transmitter and receiver used.

A fiberoptic cable has two parts: the core (center or inside) and a cladding (outside covering). These two parts of the fiber work together to cause something called *total internal reflection*, which is the key to fiberoptics. The light beam is focused on the core of the fiber, and it begins its journey down the fiber. Soon, because of a turn in the fiber or the direction at which the light originally entered the



Source: Corning

Figure 1-8 *Light travels down the glass.*

fiber, the light reaches the outside edge of the core. Normally, it would simply exit the fiber at this point, but this is where the cladding helps. When the light hits the cladding (which is made of a material selected especially because it reacts differently to light than the core material), instead of going on straight, it reflects. This creates a tunnel effect in which the light bounces its way down the fiber until it exits at the other end of the fiber.

Facts about Fiberoptics

Everyone has a story to tell when asked about fiber. Many of the myths and facts get confused and confusing. Thus we should understand just why everyone is so excited about the use of fiberoptics. Let's start with the facts first:

1. Optical fiber will be the backbone of the information superhighway, transporting voice, video, and data to businesses, schools, hospitals, and homes. Demands for information continue to increase so much that the maximum available transport rates are doubling approximately every two years. Because of this rapid growth, electronic functions in communications networks eventually will be replaced by photonic functions, which provide higher information-carrying capacity.

2. Fiberoptics are needed because coaxial television cables are capable of carrying more information than copper wire (unshielded twisted-pair wire). Computer and telephone companies need something with which to compete with the CATV companies. This also means that the fiber wires will allow the telephone companies to offer newer services. A new service being offered to consumers known as *very-high-bit-rate digital subscriber line* (VDSL) will bring telephony, TV, Internet access, and high-speed future services to the door. Yet this will depend on fiber to really achieve the result. Currently, the telephone companies are using a *hybrid fiber and coaxial* (HFC) service to offer VDSL.

3. Currently, all new undersea cables are made of optical fibers. This is crucial to the economic installation of high-density transmission systems. The cost of the fiber as opposed to the cost of copper makes the undersea cable more attractive and readily available. Look at the cost reductions in getting a trans-Atlantic circuit since the introduction of fiber. Costs literally dove down to more affordable communications for corporate connectivity internationally.

4. Many believe that 98 percent of copper wire will be replaced by fiberoptic cable, including at the local loop to the residence. This belief is one we can all take to the bank. Copper has many problems in distribution and maintenance. Fiber becomes far more economical. Logic, therefore, points to the deployment of more fiber to every facet of communications. Fiberoptic cable installed in place of copper wire that already requires replacing is less expensive. Because it only needs repeaters to amplify the signals every six miles instead of every mile for copper, the cost of installation is much less.

5. Optical fiber phone lines cannot be bugged or tapped easily. If one were to attempt to tap into the fiber, the cable would be broken in the process. This would trip alarms on the link and cause maintenance and surveillance personnel to take notice. Moreover, to rejoin the cable is more difficult, eliminating the novice from the process of tapping into a fiber system. By breaking into the cable, the light flow is disrupted (Figure 1-9). By splicing the cable improperly, loss and transmission impairments become highly

problematic. Actually, the light's reflections and refractions can be changed significantly, causing character changes in the cable. Therefore, only skilled personnel today can splice the cables properly.

6. A fiber is thinner than a human hair. Fibers are 8 to 10 microns or 50 to 62.5 microns thick. One micron (1 μm) is 1/250th the thickness of a human hair. This thickness (thinness) represents the advantages of the glass itself. It is lighter and easier to handle. It is immune to the mechanical problems of copper. It carries thousands of times the information of copper wire.

7. As radio spectrum becomes more scarce and the need for more information-carrying capacity increases, many utility companies are finding it cost-effective to install fiberoptic communications networks.

Fiber Myths

Many common misconceptions about optical fiber technology slip into any discussion. Optical fiber, optical systems, optical networks, optical technology—What does this "opto" jargon mean? It means optoelectronic technology: the transmission of voice, data, and video using pulses of light instead of electricity. Because we discussed the facts earlier, we should now clear up some of the misconceptions related to fiber and consider "the facts" about fiber's technical merits and capabilities. The myths include the following:

1. *Fiber is the most expensive wiring option.* Actually, fiber is exceptionally cost competitive when compared with coaxial cable and copper twisted-pair cable for most applications. Over the long term, fiber is actually the least expensive option.

When considering fiber, it is important to look at the total picture. Factors to consider when projecting network costs are the life of the network, the life of the system, the need to upgrade the system for future capacity requirements, and the possibility of generating revenue by leasing reserve capacity to other carriers. Compared

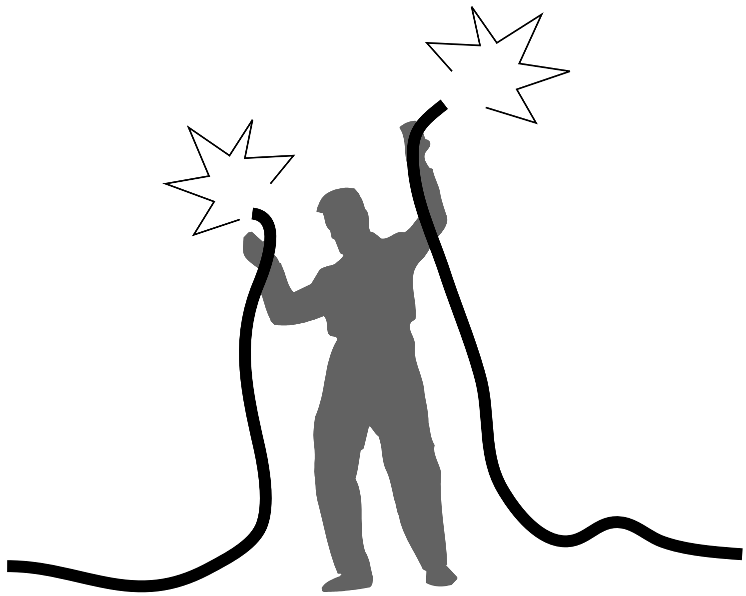


Figure 1-9 Breaking the fiber disrupts the flow of light along the cable.

with copper twisted-pair cable, optical communications systems exhibit a much lower *bit error rate* (BER) while operating at much higher data rates. As a result, data transmission is both faster and more reliable over optical fiber systems. In fact, installing extra fiber provides a bigger bang for the installation buck by preventing disruption and additional expense when it is time to upgrade. Optical fiber is not *hardware-dependent,* which means that fiber systems can be upgraded as new transmission technologies become available.

The biggest chunk of new network costs is usually installation, so it makes sense to take advantage of the opportunity to meet tomorrow's requirements by installing fiber today.

2. *Unshielded twisted-pair cable can be used for high-speed data applications.* When you transmit above 100 Mbps, fiber is the only medium that can be used confidently. As a stopgap measure, some high-speed copper wire systems are being offered today. However, these systems may require rewiring with special wire, such as a specially rated version of shielded twisted-pair cable. Even with

this special copper wire, questions still remain as to whether the system can transmit 100 Mbps over typical distances.

3. *Only high-speed systems need fiber.* Fiber can be used effectively for any system. When demands dictate, new electronics can be installed as upgrades to higher speeds. Error-free transmission capability is a critical aspect of any modern communications system. Many present-day and virtually all future communications networks will require the extensive bandwidth and flexibility of optical fiber.

4. *Fiber is highly technical and very difficult to handle.* Installing fiberoptic networks is predictable and standardized. Because fiber cable is smaller, lighter, and more flexible than other types of cable, some installers feel that it is actually easier to install fiber.

5. *Fiber is extremely fragile.* Glass fiber is actually stronger than steel. With an average tensile breaking strength of 600,000 pounds per square inch, fiber exceeds the strength requirements of all of today's communications applications.

Types of Fibers

The differences among fibers are their core sizes (the light-carrying region of the fiber). Multimode cable is made of multiple strands of glass fibers and has a much larger core than single-mode fiber.

Multimode cables have a combined diameter in the 50- to 100-micron range. Each fiber in a multimode cable is capable of carrying a different signal independent from those on the other fibers in the cable bundle. These larger core sizes generally have greater bandwidth and are easier to couple and interconnect. They enable hundreds of rays of light propagate through the fiber simultaneously. Multimode fiber today is used primarily in premise applications, where transmission distances are less than 2 kilometers.

Single-mode fiber is a single strand of glass that has a much smaller core, enabling only one mode of light to propagate through the core. Single-mode fiber has a higher bandwidth than multimode and for this reason, is the ideal transmission medium for many applications. The standard single-mode fiber core is approximately 8 to 10 microns in diameter. Because of its greater information-carrying capacity, single-mode fiber typically is used for longer distances and higher-bandwidth applications.

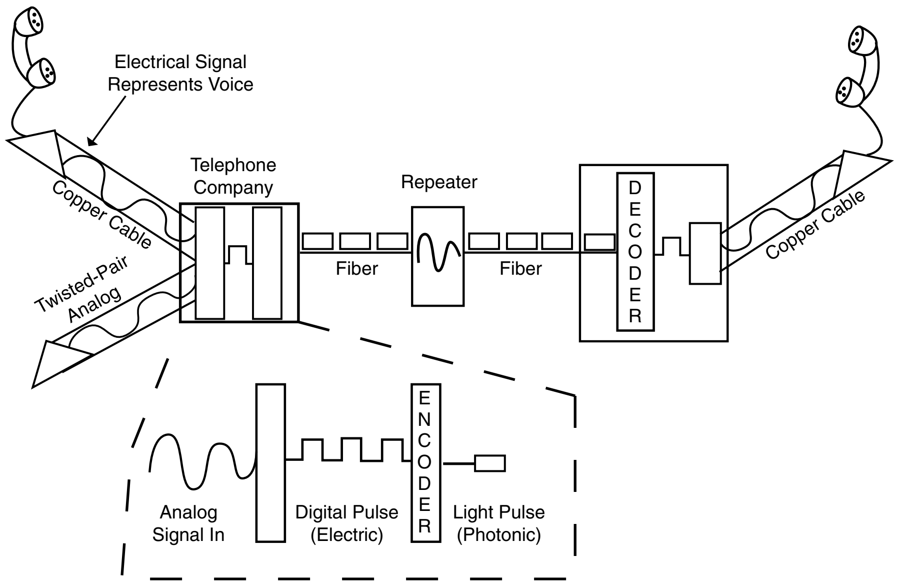
Although it may appear that multimode fibers have higher information-carrying capacity, this is not the case. Single-mode fibers retain the integrity of each light pulse over a longer distance, which enables more information to be transmitted. This is why multimode fibers are used for shorter distances and more often in premises at corporate locations (such as, high-rise offices, campus environments, and so on).

An Application of Fiberoptics

How are fiberoptics used in every day life? A basic telephone conversation can be used as an analogy for this discussion. In the North American telecommunications system, a call is transmitted from one end through an electric cable (copper) to an encoder, which transmits a signal through a fiberoptic (glass) cable. It then travels through a repeater, back through the cable, into a decoder and through an electric cable (copper) into the phone line on the other end. This transition is shown in Figure 1-10 for the flow of communications.

The sound waves that your voice generates become waves of electricity in the mouthpiece of your telephone. Rather than electricity flowing through copper wire to the final destination, fiberoptics enables electricity to pass through the encoder, which measures the waves of electricity 8000 times each second. The encoder then converts these waves into on/off pulses of light (operating as invisible infrared light). The pulses are digitized, enabling them to be read by the telephone system. The digitized message is received at the decoder. The decoder converts the laser light back into electricity. These electrical waves are changed into the sound that you hear on the phone. This same process works not only for the telephone but also for other sources that transmit data (such as, computers, televisions, and so on).

Figure 1-10
The flow of a call through the North American tele-communications system



The amount of data that can be carried is directly proportional to the transmission systems' coders/decoders used and the equipment in the middle. The higher the transport rates, the more calls or the more data that can be carried. The fiber systems use combinations of frequency- and time-division multiplexing. *Time-division multiplexing* (TDM) is used when sampling the input from telephones or computer terminals. Using this clocking (sampling) rate of 8,000 samples per second, multiplexed signals can be received from multiple inputs. From there, *frequency-division multiplexing* (FDM)[2] is used to combine the light beams operating at a certain wavelength on the fibers themselves. This is shown in Figure 1-11, where the combination of TDM and FDM is illustrated.

As mentioned earlier, AT&T Bell Labs scientists became interested in light wave communication in the mid-1960s, when it became

[2]This is also called wave-division multiplexing because different signals are multiplexed at different wavelengths together.

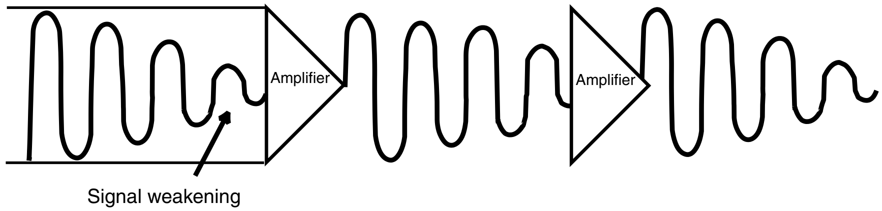


Figure 1-11 The combination of TDM and FDM on fiber

apparent that light waves had an enormous capacity for carrying information and were immune to electrical interference. Advances in lasers, light-emitting diodes, repeaters, connectors, photodetectors, and glass fibers in the following decades—and the realization that they could be fabricated and installed as integrated components—led to the installation of the first light-wave system in an operating telephone company in 1977.

This installation was the world's first light-wave system to provide a full range of telecommunications services—voice, data, and video-over a public switched network. The system, installed over about 1.5 miles under downtown Chicago, used glass fibers that each carried the equivalent of 672 voice channels (a T3).

Growth in Fiber-Based Systems

More than 15.5 million miles of fiber had been installed worldwide by the end of 1997. Construction continues growing at an endless pace that should reach 30 million miles by the end of 2001. China and the Far East market is expected to grow three times during the period of 2000-2003.

The services using fiberoptic systems are provided by all the telecommunications providers/carriers. The long-distance companies (AT&T, MCI/WorldCom, British Telecom) have been using fiberoptics for decades. Many others, such as the competitive local exchange carriers (CLECs), CATV companies, electric utility companies, and the incumbent local exchange carriers (ILECs),[3] are relatively new in this portion of the industry. The regional Bell operating companies (RBOCs) have a great deal of fiber in place within their major operating cities. They are now looking to expand their capacity as cheaply as possible because of the embedded copper plant that is rapidly becoming a liability. The newer carriers (like the CLECs) are planning to build networks based on new fiberoptics that are significantly less expensive than those used by their competitors. Their goal is to enter the market with a sufficiently attractive cost per minute for voice calls and cost per bit for data transmission to attract users to them. The cost per minute has long been the measure of data and voice transmissions.

A T3 operating at nearly 45 Mbps costs from US$80,000 to US$100,000 per month from the East Coast to West Coast. This makes the cost of transmission very reasonably priced when all things are compared. Let's look at the overall cost per minute for a 45-Mbps link. At US$80,000 per month, this can be priced as shown in Table 1-2 to keep things straight.

One can see the differences by using the T3, for example. However, prior to having the fiber-based networks, the carriers charged much more for the service on copper. Using an analogy of those costs, the costs would be far more dramatic, as shown in Table 1-3 for a copper-based architecture in the past. In this scenario, using a copper cable plant, the cost per T3 from East Coast to West Coast on the carrier networks varied between $560,000, $280,000, and $175,000 per month based on variables of length of agreement, cities connected, and so on.

---

[3] The Bell Systems LECs are more experienced in using fiber since the 1970s and 1980s.

Table 1-2

Comparing the Costs of Using a Fiber Link for T3 Access

T3 Line East to West Coast	Cost per Item
Per month	$80,000
Per day based on a 20-workday month	$ 4,000
Per hour based on a 8-hour workday	$ 500
Per minute at 60 minutes per hour	$ 8.33
Per second at 60 seconds per minute	$ 0.14
Per bit at 45 million bits per second	$ 0.000000003+

Table 1-3

Comparing the Cost of Using a Copper-Based T3 Access Link

Item	@ $560,000/ Month	@ $280,00/ Month	@ $175,000/ Month
Cost per day with 20-day month	$28,000	$14,000	$8,750
Cost per hour with 8-hour day	$3,500	$1,750	$1,094
Cost per minute	$58.34	$29.17	$18.23
Cost per second	$0.972	$0.49	$0.30
Cost per bit	$0.000000021	$0.000000012	$0.000000007

The Emergence of Wavelength-Division Multiplexing

As early as 1988, *synchronous optical networking* (SONET) and *synchronous digital hierarchy* (SDH) were the hottest discussion topic in terms of the emerging backbone fiber standards of all future telecommunications networks. Both SONET and SDH were seen as the panacea for carriers in developing multiplexing standards and techniques to reinforce the network. In 1997, *wavelength-division* *multiplexing* (WDM) suddenly became the big-ticket item. Managers, designers, and engineers alike saw the benefit that multiple wavelengths could add to the capacity of fiber-based networks. Many colors of light[4] increase the capacity of the installed fiber to 320 Gbps and in the future 1.6 *terabits per second* (Tbps)[5] and beyond. Theoretical limits of fiber today are around 30 to 40 Tbps, but with some changes, in the future we may see 100-Tbps possibilities.

SONET and SDH standards were designed originally for the TDM systems prevalent in the 1980s. Using TDM, a data stream at a higher bit rate is generated directly by multiplexing lower-bit-rate channels. High-capacity TDM systems operate at levels up to OC-192, or 10 Gbps. The problem comes with moving to higher bandwidth speeds at OC-768 and above. Current TDM equipment has trouble operating at these higher speeds.

WDM, in contrast, can carry multiple data bit rates, enabling multiple channels to be carried on a single fiber. The technique quite literally uses different colors of light down the same fiber to carry different channels of information, which are then separated out at the distant end by a receiver that identifies each color. All optical networks employing WDM with add/drop multiplexers and cross-connects permit this. Dense WDM (DWDM) systems multiplex 32 or more wavelengths in the 1550-nanometer range, increase capacity on existing fiber, and are data-rate-transparent.

DWDM ring systems can be connected with A*synchronous Transfer Mode* (ATM) switches and *Internet Protocol* (IP) routers. ATM networks are expected to use SONET/SDH physical-layer interfaces with OC-12 add/drop multiplexers. ATM can carry voice, video, and data communications in the same transport and switching equipment.

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[4]Although I refer to many colors of light, the two primary lasers used are red and blue, with variations on the wavelength of each. Variations can be considered like shades of red and shades of blue.

[5]Terabits per second is trillions of bits per second.

In the future, optical technology and advanced optical switching technologies will emerge that extend the capability of the optical layer. These technologies will include optical switching for recovery from failures as well as expansion of the add/drop multiplexing function. The first optical cross-connect systems will route a particular wavelength from one fiber route to another without conversion back to an electronic form.

ACRONYMS

ADM	add-drop multiplexer
AM	Amplitude Modulation
ANSI	American National Standards Institute
ASP	Application Service Provider
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode
AUG	Administrative Unit Group
BER	Bit Error Rate
B-ISDN	Broadband Integrated Services Digital Network
BRA	Basic Rate Access
BSC	Bisynchronous Communications (protocol)
CAN	campus area network
CATV	Cable television
CBCU	Centralized Broadband Control Unit
CCIS	Common Channel Inter-office Signaling
CCR	Customer Controlled Reconfiguration
CCS	Common Channel Signaling
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CLEC	Competitive Local Exchange Carrier
CO	Central Office
CODEC	COder-DECoder
CPE	Customer Premises Equipment
CPI	Computer-PBX Interface
DCS	Digital Cross-Connect System
DLC	Digital Loop Carrier
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense Wave Division Multiplexing
ECSA	Exchange Carriers Standards Association

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EDFA	Erbium Doped Fiber Amplifiers
EIA	Electronics Industry Association
ETSI	European Telecommunications Standards Institute
FDDI	Fiber Distributed Data Interface
FDM	frequency division multiplexing
FM	Frequency Modulation
FR	Frame Relay
FSAN	Full Service Access Networks
FSK	Frequency Shift Keying
Gbps	Gigabits Per Second
HFC	Hybrid Fiber and Coax
IC	Integrated Circuit
ICP	Integrated Communications Provider
IEC	Inter Exchange Carrier
ILEC	Incumbent Local Exchange Carrier
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ITU	International Telecommunications Union
ITU-TS	ITU-Telecommunications Standardization Sector
IWU	Inter-Working Unit
IXC	Interexchange Carrier
Kbps	Kilobits Per Second
LAN	Local Area Network
LEC	Local Exchange Carrier
LMDS	Local Multipoint Distribution Services
LTE	line terminating equipment
MAC	Media Access Control
MAN	Metropolitan Area Network
Mbps	Megabits Per Second
MEMS	Micro-Electromechanical Systems
MMDS	Multichannel Multipoint Distribution Services
MOR	Multi-wavelength optical repeaters
MPLS	Multi-Protocol Label Switching

MSOH	Multiplexer Overhead
MTP	Message Transfer Part
NIC	Network Interface Card
NID	Network Interface Device
NIU	Network Interface Unit
NMS	Network Management System
NMP	Network Management Protocol
NNI	Network Node Interface
OADM	Optical Add/Drop Multiplexer
OAM&P	Operations, administration, maintenance, and provisioning services
OBLSR	Optical Bi-directional Line Switched Rings
OC	Optical Carrier
OEO	Optical to Electrical and Then Back to Optical Again
ONI	Optical Network Interface
ONU	Optical Network Unit
OSI	Open Systems Interconnect
OSNR	Optical Signal-to-Noise Ratio
OTDM	Optical Time Division Multiplexing
O-VPN	Optical Virtual Private Network
OXC	Optical cross-connect
PDH	Plesiochronous Digital Hierarchy
PM	Phase Modulation
PoF	Plastic Optical Fiber
POH	Path Overhead
PISK	Polarity Modulation or Polarity Inversion Shift Keying
PON	Passive Optical Network
POP	Point-of-presence
POTS	Plain Old Telephone Service
PSK	Phase Shift Keying
PTE	Path Terminating Equipment
PTTs	Post Telephone and Telegraph companies
QAM	Quadrature Amplitude Modulation

QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RBB	Residential Broadband
RBOC	Regional Bell Operating Company
RF	Radio Frequency
RFC	Request for Comment
RG	Residential Gateway
ROI	Return on Investment
RSOH	Repeater (or Regenerator) Section Overhead
RSVP	Resource Reservation Services Protocol
SAN	Storage Area Network
SAR	Segmentation and Reassembly
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
SPE	Synchronous Payload Envelope
STS	Synchronous Transport Signal
STS-N	Synchronous Transport Signal level N
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time-Division Multiplexing
TE	Terminal Equipment
TIA	Telecommunications Industry Association
TS	Transport Stream
TUG	Tributary Unit Group
UNI	User Network Interface
URL	Uniform Resource Locator
VC	Virtual Container
VDSL	Very-high bit rate digital subscriber line
VoD	Video on Demand
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VSB	Vestigial Sideband
VT	Virtual Tributary

VWP	Virtual Wavelength Path
WAN	Wide Area Network
WDM	Wavelength Division Multiplexer
WIXC	Wavelength Interchange Cross-Connect
WP	Wavelength Path
WSXC	Wavelength Selective Cross-Connect

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GLOSSARY

Add/drop The process where a part of the information carried in a transmission system is demultiplexed (dropped) at an intermediate point and different information is multiplexed (added) for subsequent transmission. The remaining traffic passes straight through the multiplexer without additional processing.

Add/Drop Multiplexer (ADM) A multiplexer capable of extracting and inserting lower-rate signals from a higher-rate multiplexed signal without completely demultiplexing the signal.

Alarm Indicating Signal (AIS) A code sent downstream indicating an upstream failure has occurred. SONET defines four categories of AIS: Line AIS, STS Path AIS, VT Path AIS, and DSN AIS.

All-optical network (AON) A term first used to describe the world's first WDM network test bed that was architected and implemented at MIT's Lincoln Laboratory. Today the term is used to describe optical network environments that exploit multiple channel wavelengths for switching, routing, or distribution, using light to the almost total exclusion of electronics.

Alternate Mark Inversion (AMI) The line-coding format in transmission systems where successive ones (marks) are alternatively inverted (sent with polarity opposite that of the preceding mark).

American National Standards Institute (ANSI) A membership organization that develops U.S. standards and coordinates U.S. participation in the International Standards Organization (ISO).

Asynchronous A network where transmission system payloads are not synchronized and each network terminal runs on its own clock.

Asynchronous Transfer Mode (ATM) A multiplexing/switching technique in which information is organized into fixed-length cells with each cell consisting of an identification header field

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and an information field. The transfer mode is asynchronous in the sense that the use of the cells depends on the required or instantaneous bit rate.

Attenuation The reduction of signal magnitude or signal loss usually expressed in decibels.

Automatic Protection Switching (APS) The capability of a network element to detect a failed working line and switch the service to a spare (protection) line. 1+1 APS pairs a protection line with each working line. 1:n APS provides one protection line for every n working lines.

Bandwidth The carrying capacity or size of a communications channel; usually expressed in hertz (cycles per second) for analog circuits (the original meaning of the term) and in bits per second (bps) for digital circuits (newer meaning).

Baseband A method of communication in which a signal is transmitted at its original frequency without being impressed on a carrier.

Baud A unit of signaling speed equal to the number of signal symbols per second, which may or may not be equal to the data rate in bits per second.

Beamsplitter An optical device, such as a partially reflecting mirror, that splits a beam of light into two or more beams. Used in fiber optics for directional couplers.

Bending loss Attenuation caused by high-order modes radiating from the outside of a fiber optic waveguide, which occur when the fiber is bent around a small radius.

Bend radius The smallest radius an optical fiber or fiber cable can bend before increased attenuation or breakage occurs.

Bi-directional Operating in both directions. Bi-directional APS enables protection switching to be initiated by either end of the line.

Broadband Integrated Services Digital Network (BISDN) A single ISDN network that can handle voice, data, and eventually video services.

Bit The smallest unit of information upon which digital communications are based; also an electrical or optical pulse that carries this information. It is one binary digit, or a pulse of data.

BITE Built-in test equipment. Features designed into a piece of equipment that enable an online diagnosis of failures and operating status.

Bit Error Rate (BER) The number of coding violations detected in a unit of time, usually one second. Bit Error rate (BER) is calculated with this formula: BER = errored bits received/total bits sent.

Block Error Rate (BLER) One of the underlying concepts of error performance is the notion of Errored Blocks, that is, blocks in which one or more bits are in error. A block is a set of consecutive bits associated with the path or section monitored by means of an Error Detection Code (EDC), such as Bit Interleaved Parity (BIP). Block Error rate (BLER) is calculated with the formula: BLER = errored blocks received/total blocks sent.

Bit error versus block error Error rate statistics play a key role in measuring the performance of a network. As errors increase, user payload (especially data) must be retransmitted. The end effect is the creation of more (non-revenue) traffic in the network.

Bit-Interleaved Parity (BIP) A parity check that groups all the bits in a block into units (such as byte) and then performs a parity check for each bit position in a group.

Bit stuffing In asynchronous systems, a technique used to synchronize asynchronous signals to a common rate before multiplexing.

Bit synchronous A way of mapping payload into virtual tributaries (VTs) that synchronizes all inputs into the VTs, but does not capture any framing information or enable access to subrate channels carried in each input. For example, bit synchronous mapping of a channeled DS1 into a VT1.5 does not provide access to the DS0 channels carried by the DS1.

Bits per second (bps) The number of bits passing a point every second. The transmission rate for digital information.

Broadband A method of communication where the signal is transmitted by a high-frequency carrier. Services requiring 50–600 Mbps transport capacity.

Byte interleaved Bytes from each STS-1 are placed in sequence in a multiplexed or concatenated STS-N signal.

Byte synchronous A way of mapping payload into virtual tributaries (VTs) that synchronizes all inputs into the VTs, captures framing information, and enables access to subrate channels carried in each input.

Cable One or more optical fibers enclosed within protective covering(s) and strength members.

Cable assembly A cable that is connector-terminated and ready for installation.

Cable plant The cable plant consists of all the optical elements including fiber connectors, splices, and so on between a transmitter and a receiver.

Carrier class Carrier class refers to products designed specifically to meet the capacity, performance scalability, availability, and network management requirements of network service providers.

Community antenna television (CATV) A television distribution method whereby signals from distant stations are received, amplified, and then transmitted by coaxial or fiber cable or microwave links to subscribers. This term is now typically used to refer to cable TV.

CCITT The technical organs of the United Nations specialized agency for telecommunications, now the International Telecommunications Union—Telecom. They function through international committees of telephone administrations and private operating agencies.

Central office A common carrier switching office in which users' lines terminate. The nerve center of a telephone system.

CEPT European Conference of Postal and Telecommunications Administrations. The CEPT format defines the 2.048-Mbps European E1 signal made up of 32 voice-frequency channels.

Channel A generic term for a communications path on a given medium; multiplexing techniques enable providers to put multiple channels over a single medium.

Circuit A communications path or network; usually a pair of channels providing bi-directional communication.

Circuit switching A switching system that establishes a dedicated physical communications connection between end points, through the network, for the duration of the communications session; this is most often contrasted with packet switching in data communications transmissions.

Cladding Material that surrounds the core of an optical fiber. Its lower index of refraction, compared to that of the core, causes the transmitted light to travel down the core.

Concatenate The linking together of various data structures, such as two bandwidths joined to form a single bandwidth.

Concatenated VT A virtual tributary (VT × Nc) which is composed of N × VTs combined. Its payload is transported as a single entity rather than separate signals.

Connection-oriented A term applied to network architectures and services that require the establishment of an end-to-end, predefined circuit prior to the start of a communications session. Frame Relay circuits are examples of connection-oriented sessions.

Core The light-conducting central portion of an optical fiber, composed of material with a higher index of refraction than the cladding. The portion of the fiber that transmits light.

Cyclic Redundancy Check (CRC) A technique for using overhead bits to detect transmission errors.

Dark fiber Fiber-optic cables that have been laid but have no illuminating signals in them.

Data communications channels OAM&P channels in SONET that enable communications between intelligent controllers and individual network nodes as well as inter-node communications.

Data rate The number of bits of information in a transmission system, expressed in bits per second (bps), and which may or may not be equal to the signal or baud rate.

DB Decibel.

DBc Decibel relative to a carrier level.

DBu Decibels relative to microwatt.

DBm Decibels relative to milliwatt.

Defect A limited interruption in the capability of an item to perform a required function.

Demultiplexer A module that separates two or more signals previously combined by compatible multiplexing equipment.

Demultiplexing A process applied to a multiplex signal for recovering signals combined within it and for restoring the distinct individual channels of the signals.

Dense Wave Division Multiplexing (DWDM) An optical multiplexing technique used to increase the carrying capacity of a fiber network beyond what can currently be accomplished by time division multiplexing (TDM) techniques. Different wavelengths of light are used to transmit multiple streams of information along a single fiber with minimal interference. DWDM has been mainly deployed as a point-to-point, static overlay to the optical TDM network to create "virtual fiber." As such, DWDM is the precursor to optical networking. DWDM has drastically reduced the cost of transport by reducing the number of electrical regenerators required and sharing a single optical amplifier over multiple signals through the use of EDFAs.

Dielectric A material with both conductive and insulating electromagnetic properties. A dielectric thin-film material exhibits far more transmission than absorption at the wavelength of interest.

Digital cross-connect (DCS) An electronic cross-connect that has access to lower-rate channels in higher-rate multiplexed signals and can electronically rearrange (cross-connect) those channels.

Digital signal An electrical or optical signal that varies in discrete steps. Electrical signals are coded as voltages; optical signals are coded as pulses of light.

Dope Thick liquid or paste used to prepare a surface or a varnish-like substance used for waterproofing or strengthening a material.

DSX-1 May refer to either a cross-connect for DS1 rate signals or the signals cross-connected at DSX-1.

DSX-3 May refer to either a cross-connect for DS3 rate signals or the signals cross-connected at DSX-3.

Exchange Carrier Standards Association (ECSA) An organization that specifies telecommunications standards for ANSI.

Electromagnetic interference (EMI) Any electrical or electromagnetic interference that causes undesirable response, degradation, or failure in electronic equipment. Optical fibers neither emit nor receive EMI.

Envelope capacity The number of bytes the payload envelope of a single frame can carry. The SONET STS payload envelope is the 783 bytes of the STS-1 frame available to carry a signal. Each virtual tributary (VT) has an envelope capacity defined as the number of bytes in the virtual tributary less the bytes used by VT overhead.

E/O Abbreviation for electrical-to-optical converter.

Erbium-Doped Fiber Amplifier (EDFA) A key enabling technology of DWDM, EDFAs enable the simultaneous amplification of multiple signals in the 1,500 nanometer region, such as multiple 2.5 Gbps channels, in the optical domain. EDFAs drastically increase the spacings required between regenerators, which are costly network elements because they (1) require optical/electrical/optical conversions of a signal and (2) operate on a single digital signal, such as a single SONET or SDH optical signal. DWDM systems using EDFAs can increase regenerator spacings of transmissions to 500–800 km at 2.5 Gbps. EDFAs are far less expensive than regenerators and can typically be spaced 80–120 km apart at 2.5 Gbps, depending on the quality of the fiber plant and the design goals of the DWDM system.

Enterprise systems connection (ESCON) A duplex optical connector used for computer-to computer data exchanges.

Fiber Distributed Data Interface (FDDI) A dual counter-rotating ring local area network or a connector used in a dual counter-rotating ring local area network.

Far End Block Error (FEBE) A message sent back upstream that a receiving network element is detecting errors, usually a coding violation. *See* Remote Error Indication (REI).

Fiber The structure that guides light in a fiber optic system.

Fiber channel An industry-standard specification that originated in Great Britain that details computer channel communications over fiber optics at transmission speeds from 132 Mbps to 1062.5 Mbps at distances of up to 10 kilometers.

Fiber-to-the-Curb (FTTC) Fiber optic service to a node connected by wires to several nearby homes, typically on a block.

Fiber-to-the-Home (FTTH) Fiber optic service to a node located inside an individual home.

Fiber-to-the-Loop (FTTL) Fiber optic service to a node that is located in a neighborhood.

Fixed stuff A bit or byte whose function is reserved. Fixed stuff locations, sometimes called reserved locations, do not carry overhead or payload.

Framing A method of distinguishing digital channels that have been multiplexed together.

Frequency The number of cycles of periodic activity that occur in a discrete amount of time.

Gallium aluminum arsenide Generally used for short wavelength light emitters.

Gallium arsenide Used in light emitters.

Gigabits per second (Gbps) One billion bits per second.

Graded-index fiber Optical fiber in which the refractive index of the core is in the form of a parabolic curve, decreasing toward the cladding.

Grooming Consolidating or segregating traffic for efficiency.

Half-duplex A bi-directional link that is limited to a one-way transfer of data; that is, data can't be sent both ways at the same time.

Hard-optics The hardware technologies that create and transport light, such as DWDM, FEC, Raman amplification, tunable dispersion compensators, Variable Optical Attenuators, dynamic spectral gain compensators, Micro-Electro-Mechanical Systems (MEMS), and Optical Spectrum Analyzers (OSAs).

Index of refraction Also refractive index. The ratio of the velocity of light in free space to the velocity of light in a fiber material.

Infrared (IR) Light from the region of the spectrum with wavelengths between 750nm (red) and 0.1mm (microwave).

Intelligent optical network A dynamic flexible network of virtual lightpaths that is "light" from end to end and delivers an abundance of cost-effective, usable bandwidth.

Intelligent optical networking Bringing network intelligence to the optical domain; the creation, configuration, and management of virtual lightpaths within the optical domain. A new class of products for the development of an intelligent optical network.

Interleave The capability of SONET to mix together and transport different types of input signals in an efficient manner, thus enabling higher-transmission rates.

Isochronous All devices in the network derive their timing signal directly or indirectly from the same primary reference clock.

Jacket The outer, protective covering of the cable.

Jitter Small and rapid variations in the timing of a waveform due to noise, changes in component characteristics, supply voltages, imperfect synchronizing circuits, and so on.

Kilobits per second One thousand bits per second.

Lambda (l) An optical wavelength.

Laser An acronym for light amplification by the stimulated emission of radiation. A light source that produces, through stimulated emission, coherent, near-monochromatic light. Lasers in fiber optics are usually solid-state semiconductor types.

Light In a strict sense, the region of the electromagnetic spectrum that can be perceived by human vision, designated by the visible spectrum, and nominally covering the wavelength range of 0.4 μm to 0.7 μm. In the laser and optical communication fields, custom and practice have extended usage of the term to include the much broader portion of the electromagnetic spectrum that can be handled by the basic optical techniques used for the visible spectrum. This region has not been clearly defined. Athough, as employed by most workers in the field, it may be considered to extend from the near ultraviolet region of approximately 0.3 μm, through the visible region, and into the mid-infrared region to 30 μm.

Lightpath Analogous to virtual circuits in the ATM world, a lightpath is a virtual circuit in the optical domain that could consist of multiple spans, each using a different physical wavelength for the transmission of information across an optical network.

Line One or more SONET sections, including network elements at each end, capable of accessing, generating, and processing Line Overhead.

Line Terminating Equipment (LTE) Network elements such as add/drop multiplexers or digital cross-connect systems that can access, generate, and process Line Overhead.

Megabits per second (Mbps) One million bits per second.

Metropolitan Area Network (MAN) A network covering an area larger than a local area network (LAN); a wide area network (WAN) covering a metropolitan area. Usually, it is an interconnection of two or more LANs.

Micrometer One millionth of a meter. Abbreviated μm.

Multimode fiber An optical fiber with a core large enough to propagate more than one mode of light. The typical diameter is 62.5 micrometers.

Multiplex (MUX) To transmit two or more signals over a single channel.

Multiplexer A device for combining several channels to be by one line or fiber.

Nanometer One billionth of a meter.

Nanosecond One billionth of a second.

Narrowband Services requiring up to 1.5 Mbps transport capacity.

Network Element (NE) Any device that is part of a SONET transmission path and serves one or more of the section, line, and path-terminating functions. In SONET, the five basic network elements are

- Add/drop multiplexer
- Broadband digital cross-connect
- Wideband digital cross-connect
- Digital loop carrier
- Switch interface

Network Monitoring and Analysis (NMA) A fault management system used by RBOCs to perform network monitoring and surveillance. The NMA system has two types, facilities management and switch management. NMA is capable of performing an event correlation to determine the root cause, create trouble tickets, and track the status of outstanding tickets. NMA relies on topology information to perform event correlation. This information can come from TIRKS (via NSDB) or it can be manually entered.

Optical Carrier Level 1 (OC-1) The optical equivalent of an STS-1 signal.

Optical Carrier Level N (OC-N) The optical equivalent of an STS-N signal.

Opaque optical networks The current vision of the optical network whereby conversions from the optical to the electrical and back to the optical domain are required periodically. Such optical/electrical/optical conversions are required in order to retime the signal in the digital domain, clean up signal impairments, enable fault isolation, and provide performance monitoring (particularly of signal bit error rate). Today's optical networks take advantage of SONET/SDH frame structure for B1 byte parity checks, BER monitoring, and J0 byte path trace at a minimum. Opaque network elements will occur as gateways along extended backbones to limit the accumulation of analog signal impairments and enable performance monitoring and fault isolation.

Optical Add/Drop Multiplexer (OADM) Also called a Wavelength Add/Drop Multiplexer (WADM). An optical network element that lets specific channels of a multi-channel optical transmission system be dropped and/or added without affecting the through signals (the signals that are to be transported through the network node).

Optical amplifier A device that increases the optical signal strength without an optical-to-electrical-to-optical conversion process.

Optical carrier (OC) A designation used as a prefix denoting the optical carrier level of SONET data standards. OC-1/STS-1, OC-3/STS-3, OC-12, OC-48, and OC-192 denote transmission standards for fiber-optic data transmissions in SONET and frames at data rates of 51.84 Mbps, 155.52 Mbps, 622.08 Mbps, 2.48832 Gbps, and 9.95 Gbps, respectively. S*ee* SONET and STS.

Optical carrier (OC-x) This is a base unit found in the SONET hierarchy; the "x" represents increments of 51.84 Mbps (so OC-1 is 51.84 Mbps, OC-3 is 155 Mbps, and OC-12 is 622 Mbps). *See* Synchronous Optical Network.

Optical cross-connect (OXC or OCS) An optical network element that provides for incoming optical signals to be switched to any one of a number of outputs. Some OXCs connect fibers containing multi-channel optical signals to the input parts, demultiplex the signals, switch the signals, and recombine/remultiplex the signals to the output ports.

Optical fiber (a.k.a. fiber) A thin silica glass cable with an outer cladding material and a ≅ nine micro-meter diameter inner core with a slightly higher index of refraction than the cladding.

Optical network The optical network provides all the basic network requirements in the optical layer, namely capacity, scalability, reliability, survivability, and manageability. Today the wavelength is the fundamental object of the optical network. The long-term vision of an "all-optical network" is of a transparent optical network where signals are never converted to the electrical domain between network ingress and egress. The more practical implementation for the near term will be of an opaque optical network, that is, one that works to minimize but still includes optical/electrical/optical conversion. Optical network elements will include terminals, dynamic add/drop multiplexers, and dynamic optical cross-connects.

Optical networking The natural evolution of optical transport from a DWDM-based point-to-point transport technology to a more dynamic, intelligent networking technology. Optical networking will use any one of a number of optical multiplexing schemes to multiplex multiple channels of information onto a fiber and will add intelligence to the optical transport layer that will provide the reliability, survivability, and manageability today provided by SONET/SDH.

Optical switching products An emerging category of optical networking products that operate at the granularity of a lightpath and that provide the following functionality at a minimum: performance monitoring and management, restoration and rerouting enabled by inter-switch signaling, wavelength translation, the establishment of end-to-end lightpaths, and the delivery of customer services.

Optical transport products An emerging category of optical networking products that operate at the granularity of a lightpath and that provide the following functionality at a minimum: performance monitoring and management, restoration and rerouting, wavelength translation, and delivery of customer services. OADMs and DWDM terminals are included in this category.

OSI seven-layer model A standard architecture for data communications. Layers define the hardware and software required for multi-vendor information processing equipment to be mutually compatible.

Path A logical connection between a point where an STS or VT is multiplexed to the point where it is demultiplexed.

Path Terminating Equipment (PTE) Network elements, such as fiber-optic terminating systems, which can access, generate, and process Path Overhead.

Payload The portion of the SONET signal available to carry service signals such as DS1 and DS3. The contents of an STS SPE or VT SPE.

Photon The basic unit of light transmission used to define the lowest (physical) layer in the OSI seven-layer model.

Photonic A term coined for devices that work using photons, analogous to “electronic” for devices working with electrons

Plastic fiber An optical fiber having a plastic core and plastic cladding.

Plesiochronous A network with nodes timed by separate clock sources with almost the same timing.

Point-to-point transmission A transmission between two designated stations.

POP (Point-of-Presence) A point in the network where interexchange carrier facilities like DS3 or OC-N meet with access facilities managed by telephone companies or other service providers.

Polarization The direction of the electric field in the lightwave.

Port Hardware entity at each end of the link.

POTS Plain old telephone service.

Picosecond One trillionth of a second.

Pulse A current or voltage that changes abruptly from one value to another and back to the original value in a finite length of time.

Refractive index gradient The change in the refractive index with distance from the axis of an optical fiber.

Regenerator A device that restores a degraded digital signal for continued transmission; also called a repeater.

Ring network A network topology in which terminals are connected in a point-to-point serial fashion in an unbroken circular configuration.

Synchronous Digital Hierarchy (SDH) The ITU-T-defined world standard of transmission with a base transmission rate of 51.84 Mbps (STM-0) and is equivalent to SONET's STS-1 or OC-1 transmission rate. SDH standards were published in 1989 to address interworking between the ITU-T and ANSI transmission hierarchies. The European version of the SONET standard has two major differences: the terminology and the basic line rate in SDH is equivalent to that of the SONET OC-3/STS-3 rate (that is, 155.52 Mbps). SDH enables direct access to tributary signals without demultiplexing the composite signal. The compatibility between SDH and SONET enables internetworking at the Administrative Unit-4 (AU-4) level. SDH can support broadband services such as a broadband integrated services digital network (B-ISDN).

Silica glass Glass made mostly of silicon dioxide, SiO2, used in conventional optical fibers.

Single-mode (SM) fiber A small-core optical fiber through which only one mode will propagate. The typical diameter is eight to nine microns.

Slip An overflow (deletion) or underflow (repetition) of one frame of a signal in a receiving buffer.

Soft-optics The software technologies that package and control the light, such as the automatic power balancing of lightwave services, the auto-discovery of optical components and their capacities, fiber plant monitoring, signal equalization, path integrity verification, lightpath performance monitoring, dispersion compensation tune-ups, and optical fault diagnostics.

Splitter A device that creates multiple optical signals from a single optical signal.

Stratum A level of clock source used to categorize accuracy.

Superframe Any structure made of multiple frames. SONET recognizes superframes at the DS1 level (D4 and extended superframe) and at the VT (500 ms STS superframes).

Synchronous A network where transmission system payloads are synchronized to a master (network) clock and are traced to a reference clock.

Synchronous Optical Network (SONET) Standards for transmitting digital information over optical networks. Fiber optic transmission rates range from 51.84 Mbps to 9.95 Gbps. The base rate is known as OC-1 and runs at 51.84 Mbps. Higher rates are a multiple of this such that OC-12 is equal to 622 Mbps (12 times 51.84 Mbps).

Synchronous Transfer Module (STM) An element of the SDH transmission hierarchy. STM-1 is SDH's base-level transmission rate equal to 155 Mbps. Higher rates of STM-4, STM-16, and STM-48 are also defined.

Synchronous Payload Envelope (SPE) The major portion of the SONET frame format used to transport payload and STS path overhead. A SONET structure that carries the payload (service) in a SONET frame or virtual tributary. The STS SPE may begin anywhere in the frame's payload envelope.

STS Path Terminating Equipment (STS PTE) Equipment that terminates the SONET STS Path layer. STS PTE interprets and modifies or creates the STS Path Overhead. An NE that contains STS PTE will also contain LTE and STE.

Synchronous Transport Signal Level 1 (STS-1) The basic SONET building block signal transmitted at a 51.84 Mbps data rate.

Synchronous Transport Signal Level N (STS-N) The signal obtained by multiplexing integer multiples (N) of STS-1 signals together.

Terabits per second (Tbps) One trillion bits per second. An information-carrying capacity measure used for high-speed optical data systems.

Time Division Multiplexing (TDM) An electrical (digital) multiplexing technique used to enable multiple streams of information to share the same transmission media. For transmission at 155 Mbps or above, the electrical TDM signal is typically converted to an optical signal for transport.

Total Internal Reflection The reflection that occurs when light strikes an interface at an angle of incidence (with respect to the normal) greater than the critical angle.

Transmission The process of sending information from one point to another.

Transparent Optical Networks The original vision of the "all optical network" as a network in which a signal is transported from source to destination entirely in the optical domain. After ingress into the network, the signal is never converted to the electrical domain for analog operations such as amplification and filtering or any other purpose.

T1X1 Subcommittee A committee within ANSI that specifies SONET optical interface rates and formats.

Virtual Tributary (VT) A signal designed for the transport and switching of sub-STS-1 payloads.

Wide area network (WAN) A data communications facility involving two or more computers with the computers situated at different sites.

Wander Long-term variations in a waveform.

Waveguide A material medium that confines and guides a propagating electromagnetic wave. In the microwave regime, a waveguide normally consists of a hollow metallic conductor, generally rectangular, elliptical, or circular in a cross-section. This type of waveguide may, under certain conditions, contain a solid or gaseous dielectric material. In the optical regime, a waveguide used as a long transmission line consists of a solid dielectric filament (optical fiber), usually circular in a cross-section. In integrated optical circuits, an optical waveguide may consist of a thin dielectric film.

Wavelength A measure of the color of the light for which the performance of the fiber has been optimized. It is a length stated in nanometers (nm) or in micrometers (μm).

Wavelength division multiplexer A passive device that combines light signals with different wavelengths on different fibers onto a single fiber. The wavelength division demultiplexer performs the reverse function.

Wavelength-Division Multiplexing (WDM) Sending several signals through one fiber with different wavelengths of light.

Wideband Services requiring 1.5 to 50 Mbps transport capacity.